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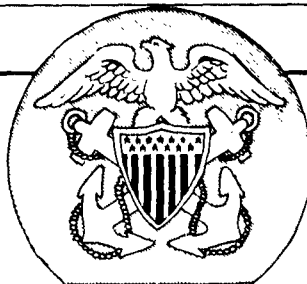*by the*

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THE EFFECT OF SIMULATED TROPICAL CLIMATE ON THE PERFORMANCE OF MARINE CORPS PERSONNEL WEARING AN INTEGRATED BODY ARMOR- LOAD CARRYING SYSTEM (BALCS)

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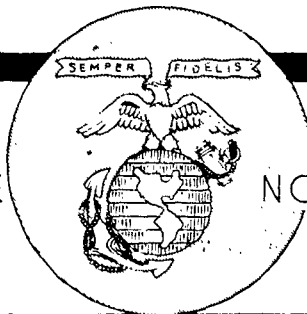
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SUMMARY

THE PROBLEM

The purpose of this study was to determine to what extent the wearing of a body armor-load carrying system (BALCS) developed by the Personnel Protection Division of the Naval Medical Field Research Laboratory and carrying a total load of 54 pounds affect the ability of a group of U. S. Marines to do a fixed amount of work under simulated tropical climatic conditions.

FINDINGS

Although the addition of the integrated body armor-load carrying system (BALCS) developed at the Naval Medical Field Research Laboratory with load produced significant increases in the several physiological parameters measured, increases were within normal physiological limits for the 45-minute period in which the subjects were exposed to the experimental conditions. Assessment of the adrenal cortical activity, as indicated by the measurements utilized in this study, suggested that neither the heat and humidity in which the subjects exercised nor the wearing of the BALCS was of a sufficient magnitude to cause measurable stress.

APPLICATION

The addition of the protective garment to the usual environmental clothing and equipment, particularly under conditions of high temperature and high humidity along with increased activity, could result in thermal stress. It was hoped from this study to determine the magnitude of the physiological stress imposed by the wearing of this protective garment under adverse climatic conditions. This information then could be used as a basis for making recommendations as to the period of time a well-trained combat infantry Marine could be expected to maintain safe physiological limits when working in the heat with this equipment.

ACKNOWLEDGMENTS

ABSTRACT

The objective of this study was to determine the physiologic stress imposed on physically fit Marine Corps infantrymen when wearing the Naval Medical Field Research Laboratory body armor-load carrying system with full load (BALCS) (total weight, 54 pounds). Study was carried out under simulated tropical climatic conditions.

Subjects exercised on a' treadmill positioned for a 3 per cent grade and rotating at 3.5 mph. This work was carried on for 45 minutes at dry bulb temperatures of 26.7, 29.4, 32.2, and 35.0 degrees centigrade with a constant relative humidity of 75 per cent. Men were tested at each of these four environmental conditions with and without BALCS. Total load carried by each subject was 54 pounds. The differences in pre- and post-exercise measurements served as the raw data for each of the physiological parameters, and the statistical procedure was to subject the differences to an analysis of variance.

The changes in physiological parameters attributable to the wearing of the BALCS with load were statistically significant for rectal and skin temperatures, heat gain, and sweat loss. However, the magnitude of the increase was within normal physiological limits. Subjects approached unsafe limits only at the extreme exercise condition (wearing BALCS with load at 35°C) and for only the sweat loss variable. Accordingly, it is concluded that the wearing of BALCS with load did not unduly affect the operational efficiency of these subjects under the conditions of this study.

The Effect of Simulated Tropical Climate on the Performance of Marine Corps Personnel Wearing an Integrated Body Armor-Load Carrying System (BALCS)

INTRODUCTION

The development of armored vests and other protective equipment for the combat infantryman has naturally raised the question of how much such added protection cost the individual in terms of operational efficiency, particularly when functioning under extreme environmental conditions.

Interest in this problem has been demonstrated by both the Army and the Marine Corps. Our laboratory has designed an integrated body armor-load carrying system (BALCS) for use in combat and was particularly concerned with the results of an evaluation of a similar type of protective garment reported by Goddard et al. (1). In that study, results indicated that physically fit individuals wearing standard body armor and carrying a 50-pound load could maintain efficiency (pulse rate less than 180 beats/min and/or rectal temperature below 39°C) for an average of 19.95 minutes at a dry bulb temperature of 35°C and a relative humidity of 65 per cent when walking on a treadmill rotating at 3.5 miles per hour with a 3 per cent grade. Obviously, protective gear that impairs operational efficiency in so short a period has little practical application to the combat situation.

The object of the present study was to determine the effect of wearing a body armor-load carrying system with full load (hereinafter referred to as BALCS) on the ability of a group of physically fit Marines to perform a fixed amount of work at high temperatures and humidities. It was hoped that it would then be possible to ascertain the magnitude of the physiological stress imposed by the wearing of this protective garment at these temperature conditions. This information could then be used as a basis for making recommendations as to the period of time a well-trained combat infantry Marine could tolerate working under conditions of high temperature and high humidity while wearing this equipment.

PROCEDURES AND METHODS

Subjects

Six enlisted Marines assigned to Headquarters Battalion, Marine Corps Base, Camp Lejeune, North Carolina, served as subjects. They had been stationed at Camp Lejeune for at least a year, and in the 4 months preceding the experiment they had not been exposed to

conditions which could have produced heat acclimatization. The ages of the men ranged from 19 to 24; descriptive details are shown in Table A-1 of the appendix.

Physical Conditioning

For 2 weeks prior to the experiment, the subjects underwent a program of physical conditioning which included:

1. Hikes every other day for a total of

   a. Two 7-mile hikes without carrying a load.
   b. Two 12-mile hikes carrying a 25-pound load.
   c. Two 20-mile hikes carrying a 54-pound load (BALCS plus the usual combat gear).

2. Calisthenics - standard setting-up exercises (2) twice daily for a total period of 1-1/2 hours per day.

3. Ranger training - i.e., a combat training routine similar to that carried out by the U. S. Army Ranger School, Fort Benning, Georgia. This was utilized every other day alternating with the hikes.

4. Competitive sports - for approximately 2 hours each day the subjects were free to participate in semi-organized sports, e.g., swimming, basketball, volley ball, etc., under the supervision of a senior noncommissioned officer.

All of this training with the exception of the swimming occurred out-of-doors in February of 1959 when the average ambient temperature was 50°F and the relative humidity 70 per cent.

To indicate their progress, subjects were given the "Step Test" (3) and a Physical Fitness Test (4)* several times during the period of physical conditioning. Scores of the men before and after the

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* Although both are referred to as fitness tests, the emphasis in each case is different. The "Step Test" is a preferred measure of cardio-vascular recovery - the lower the pulse rate at a fixed time after the exercise, the higher the score. The Physical Fitness Score, on the other hand, appears to be a test of endurance since the score is based on the ability of the individual to do a maximum number of exercises in a given time and also test a greater variety of muscle groups.

training period improved in both tests. For example, their average score on the "Step Test" increased from 41.6 (poor) to 79.5 (good) and on the Physical Fitness Score from 299 (good) to 348 (excellent).

Experimental Conditions

The study was conducted at the Laboratory of Applied Physiology of the University of North Carolina in an insulated hot room built to enclose a motor-driven treadmill. The construction of this chamber is such that occupants gain heat both by radiation and by conduction. Subjects exercised on a treadmill positioned for a 3 per cent grade and rotating at 3.5 miles per hour. Exercise was carried out at dry bulb temperatures of 26.7, 29.4, 32.2, and 35.0 degrees centigrade (80, 85, 90, and 95 degrees Fahrenheit, respectively); the relative humidity was kept constant at 75 per cent. The men were tested at each of these four environmental conditions with and without load. The load consisted of a Naval Medical Field Research Laboratory experimental body armor-load carrying system (BALCS) weighted to equal 10 clips of ammunition, 2 canteens of water, entrenching tool, 1 day's rations, a 3-pound load equivalent to items of clothing which normally would be carried, rifle, helmet, and other personal gear. The total load, including the body armor, weighed 54 pounds (Figure A-1 of the appendix).

Each exercise session lasted for 45 minutes. This is approximately the time a physically fit combat Marine is expected to walk before given a rest period.

Experimental Design

A modified Latin Square design was employed in the study. There were eight test situations (conditions) consisting of exercise at four temperature levels, both with and without load. There were eight experimental days with three sessions in the morning and three in the afternoon (the maximum number that it was possible to arrange). The order of presentation of the treatments was randomized. The subjects were numbered randomly, i. e., arranged in alphabetical order of first name and designated 2, 1, 4, 3, 5, and 7.[*] It can be noted from Table A-2 of the appendix that (a) each condition was employed once in the

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[*] There were seven subjects available for study with one (#6) to be used as an alternate if necessary.

morning session and once in the afternoon session; (b) in the morning session subjects 2, 3, and 4 were used throughout; and in the afternoon session subjects 1, 5, and 7 were used throughout; and (c) in the morning session, each condition was employed exactly once by each of the morning subjects and similarly by each of the afternoon subjects.[*]

Physiological Measurements

Pulse rate: Pulse rates were taken by radial palpation just prior to the start of each exercise and at 5-minute intervals throughout the 45-minute test period. All counts were made by the same observer positioned inside the chamber and were accomplished with the treadmill in motion.

Rectal temperature: Rectal temperatures were obtained just prior to the start of each exercise and at 5-minute intervals throughout the test period, utilizing thermistor probes inserted about 8 inches into the rectum, connected with flexible leads to a multi-channel Telethermometer (Yellow Spring Instrument Company).

Skin temperature: Skin temperatures were also measured just prior to the start of each exercise and at 5-minute intervals throughout the 45-minute period. "Banjo"-type thermistors were secured by a broad elastic band to the forehead (Position No. 1), chest (Position No. 2), back (Position No. 3), and right deltoid muscle (Position No. 4). Care was taken to avoid interference with circulation. Flexible leads from the thermistors on the body were read from the same multi-channel Telethermometer used for rectal temperatures.

Heat gain: Heat gain was calculated in terms of the average changes in skin and rectal temperature which occurred during the exercise, adapting a formula suggested by Miller and Blyth (5) wherein

Heat gain (cal/kg/45 min.) = 0.83 (0.33 x change in average skin temperature + 0.67 x change in rectal temperature).

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[*] As an indication of the adequacy of the experimental design, it may be noted in Table A-3 of the appendix that the results for the group on the first day were essentially the same as for any other day of the experiment and that the day on which a particular condition was used did not affect the responses.

Sweat rate: Sweat rate was based on the difference in weight of subjects before and after exercise and expressed as kg/45 min. Subjects were carefully dried by towel and weighed in the nude on a Howe balance which has a sensitivity of ±10 grams.

Blood lactic acid: Blood lactate responses to exercise and heat were measured by determining the levels in the blood with the subjects at rest and at the conclusion of the exercise on the treadmill. A .01 ml. sample of blood for each determination was obtained by a stab wound in the finger tip.

All samples were measured in duplicate. Lactate was measured by the procedure of Barker and Summerson (6) with the modifications for a micro method as developed by Summerson and Heuwirth(7).* Determinations were made on a Coleman Junior Spectrophotometer, setting the wave length at 560μ.

Evaluation of Adrenal Cortical Function

Measurements which were made in an attempt to assess the effect of temperature and load on the activity of the adrenal cortex included eosinophil counts and sodium and potassium levels in urine and saliva.

Eosinophils: Eosinophils were stained and counted by the method described in the National Naval Medical Center Hematology Manual (8). Samples were taken from a finger stab wound immediately before and after each exercise.

Sodium-potassium ratio in urine: Urine samples were collected before and after exercise. Sodium and potassium determinations were made by direct reading after proper dilution on a Coleman Junior Spectrophotometer (Model 21), utilizing a flame photometer attachment.

Sodium and potassium in saliva: Saliva was collected while the subject chewed paraffin during a 5-minute period before and after the exercise. Electrolytes after proper dilution were determined by the same method utilized for urine.

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* Cited in reference (7) Hawk.

Statistical Analysis:

The difference in the measurements taken prior to and after completion of the 45-minute exercise period served as the raw data for each of the physiological parameters studied. An analysis of variance was carried out on these differences. The principal sources of variation were considered to arise from differences between subjects and from differences between the test conditions.

For those variables where the condition means showed a linear change (increase or decrease) as a function of temperature, regression analyses were performed using the method of least squares. The four temperatures used in the climatic chamber were plotted on the abscissa and the overall mean obtained by averaging the mean values for load and no load at each temperature served as the ordinate.

RESULTS

Pulse Rate

The resting and final pulse rates of each subject for each experimental condition are presented in Table A-4 of the appendix. A review of these and an analysis of the resting pulse rate means (Table 1) suggest that the resting pulse rates of the six subjects did not differ significantly. The analysis does indicate that there did occur day-to-day intra-individual variation in this measurement.

Table 1

Resting Pulse Rates of Subjects
(beats/min)

Group	Subject	Mean	Standard Deviation	Range	95% Confidence Limits of Means	
					LL	UL
AM	2	83.2	±10.25	68- 96	74.69	91.81
	3	90.3	± 5.18	84-100	85.92	94.58
	4	81.8	± 7.81	68- 96	75.22	88.28
PM	1	90.5	± 8.54	80-100	83.36	97.64
	5	93.5	±10.68	76-108	84.58	102.42
	7	88.0	± 9.32	80-100	80.22	95.78

An analysis of variance was undertaken in which the raw data were the differences between the pre- and post-exercise pulse rates. The results, as summarized in Table 2(a), indicated that the two expected main sources of variation (subjects and conditions) failed to contribute significantly to the differences in response noted. However, ambient temperature, one of the two principal sources of variation for conditions, was statistically significant at the 0.05 level of probability. Its co-factor load did not markedly affect the pulse rate differences. It is of interest to point out that the variance due to the effect of ambient temperature was more than three times that resulting from wearing the load. The relative contribution of temperature and load can be seen from examining the condition means and their differences (Table 2(b)). The difference between the pre- and post-exercise pulse rates for the no-load condition showed an increase of 18 beats per minute between the ambient temperature extremes (26.7° - $35.0^\circ G$), while under the condition of load the same comparison showed an increase of only 4.67 beats per minute. It is also to be noted that at two of the four ambient temperatures used (29.4° - $35.0^\circ C$), the difference in the pre- and post-exercise pulse rate was greater for the no-load condition, further evidence of the relatively small effect of load on this physiological parameter.

Table 2(c) reports the average subject means and related measures for this variable. The average pulse rate difference for the three morning subjects (Nos. 2, 3, and 4) was 4.34 beats per minute less than the average for the afternoon subjects (Nos. 1, 5, and 7). This difference as indicated in Table 2(a) (subjects and AM vs. PM terms) was not of statistical significance.
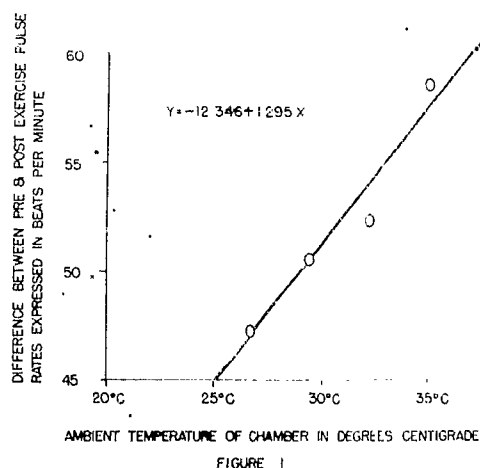
A regression analysis of the mean pre- and post-exercise pulse rate differences indicated that an increase of approximately $2.8^\circ C$ in the dry bulb temperature resulted in an increase of 3.63 beats per minute. Thus a $1.99^\circ C$ increase in dry bulb temperature results in approximately the same difference between working with and without body armor. This relationship is shown graphically in Figure 1.

$Y = -12.346 + 1.295 X$

DIFFERENCE BETWEEN PRE & POST EXERCISE PULSE RATES EXPRESSED IN BEATS PER MINUTE

AMBIENT TEMPERATURE OF CHAMBER IN DEGREES CENTIGRADE

FIGURE 1

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Table 2

Analysis of Variance of Differences Between Pre- and Post-Exercise Pulse Rates in Beats Per Minute

(a)

Source of Variation	df	Sum of Squares	Mean Squares	F
Subjects	5	865.0000	173.0000	1.918
AM vs. PM	1	225.3333	225.3333	1.409
Error	4	639.6667	159.9167	
Conditions	7	1366.6667	195.2381	2.165
Temperature	3	817.8333	272.6111	3.023*
Load	1	80.0833	80.0833	0.888
Temperature x load	3	468.7500	156.2500	1.733
(AM vs. PM) x conditions	7	862.3333	114.6190	1.271
Residual	28	2525.0000	90.1786	
Total	47	5559.0000		

*Significant at 0.05 level.

(b)   Summary of Condition Means and Differences

	Ambient Temperature				Overall Mean	Diff.	$SE_{Diff.}$
	26.7° C	29.4° C	32.2° C	35.0° C			
Load	+53.00	+48.33	+55.17	+57.67	+53.54	+2.58	±2.741
No Load	+41.67	+52.83	+49.67	+59.67	+50.96		
Overall Mean	+47.34	+50.58	+52.42	+58.67	+52.25		
Difference	+11.33	-4.50	+5.50	-2.00	+2.58		
$SE_{Diff.}$	±5.483						

(c)   Summary of Subject Means and Differences

	Subject No.	Subject Means	AM & PM Means	Diff.	$SE_{Diff.}$
AM	2	+48.25	+50.08	-4.34	±3.651
	3	+52.75			
	4	+49.25			
PM	1	+48.00	+54.42		
	5	+59.50			
	7	+55.75			

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Rectal Temperature

Table A-5 of the appendix presents the resting and final rectal temperatures of subjects at each of the experimental situations. An analysis of the resting rectal temperatures (Table 3) indicates that these varied significantly (>0.05) only between subject #4 (AM group) and subject #7 (PM group). On the other hand, the intra-individual variation for this measurement was statistically significant on each of the days that the subjects exercised.

Table 3

Resting Rectal Temperature of Subjects
(degrees centigrade).

Group	Subject	Mean	Standard Deviation	Range	95% Confidence Limits of Means	
					LL	UL
AM	2	37.2	±0.15	37.0-37.4	37.07	37.33
	3	37.1	±0.20	36.8-37.4	36.39	37.27
	4	37.1	±0.11	36.9-37.2	37.01	37.19
PM	1	37.1	±0.21	37.1-37.6	36.93	37.27
	5	37.3	±0.16	37.1-37.6	37.16	37.44
	7	37.3	±0.12	37.2-37.5	37.20	37.40

The differences between the pre- and post-exercise rectal temperatures expressed in degrees centigrade were used as the raw data for the analysis of variance. These results are summarized in Table 4(a). In this case, the two principal sources of variation, namely,

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Table 4

Analysis of Variance of Differences Between Pre- and Post-Exercise Rectal Temperatures in Degrees Centigrade

(a)

Source of Variation	df	Sum of Squares	Mean Squares	F
Subjects	5	1.4144	0.2829	5.079**
AM vs.PM	1	0.5419	0.5419	2.485
Error	4	0.8725	0.2181	
Conditions	7	1.9531	0.2790	5.009**
Temperature	3	1.3023	0.4341	7.794**
Load	1	0.5852	0.5852	10.506**
Temperature x load	3	0.0656	0.0219	0.393
(AM vs.PM) x conditions	7	0.1298	0.0185	0.332
Residual	28	1.5608	0.0557	
Total	47	5.0581		

**Significant at 0.01 level.

(b)   Summary of Condition Means and Differences

	Ambient Temperature				Overall Mean	Diff.	$SE_{Diff.}$
	26.7° C	29.4° C	32.2° C	35.0° C			
Load	+0.75	+1.02	+1.18	+1.27	+1.055	-0.222	±0.068
No Load	+0.65	+0.78	+0.88	+1.02	+0.833		
Overall Mean	+0.70	+0.90	+1.03	+1.15	+0.944		
Difference	-0.10	-0.24	-0.30	-0.25	-0.222		
$SE_{Diff.}$	±0.136						

(c)   Summary of Subject Means and Differences

	Subject No.	Subject Means	AM & PM Means	Diff.	$SE_{Diff.}$
AM	2	+0.69	+0.84	-0.21	±0.135
	3	+0.96			
	4	+0.86			
PM	1	+1.24	+1.05		
	5	+1.05			
	7	+0.86			

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subjects and conditions, both yielded F ratios which were significant at better than the 0.01 level of probability. The contribution of each of these items to the total variance was approximately equal. In other words, the variability among the subjects was about equal to that arising from the various conditions. No significant differences between the morning and afternoon groups were noted for this variable. Both the factors of temperature and load yielded F ratios significant at the 0.01 level of probability. In this situation the effect of load was a little greater than the effect resulting from the ambient temperature. None of the interaction terms was significant.

Additional support for the findings reported above can be found in the data of Table 4(b) where the condition means are reported for this variable. A progressive increase in the difference between the pre- and post-exercise rectal temperature as a function of ambient temperature occurred for both the load and no-load conditions. The increase between the ambient temperature extremes was $0.52^{\circ}C$ under the condition of load and only $0.37^{\circ}C$ for the no-load condition. When the overall mean change in rectal temperature for the two conditions (load and no load) was compared, it was found that the mean value for load was $0.22^{\circ}C$ higher than for the no-load value, a difference which was shown to be statistically significant.

Table 4(c) shows the overall mean difference between the pre- and post-exercise rectal temperatures for each subject. The mean increase in rectal temperature difference was $0.21^{\circ}C$ higher in the afternoon than in the morning, although as indicated in Table 3(a) this observed difference was not significant. A regression analysis of the mean differences between the pre- and post-rectal temperatures as a function of the ambient temperature is presented in Figure 2. The analysis showed that an increase of $2.8^{\circ}C$ in dry bulb temperature resulted in an increase of approximately $0.15^{\circ}C$ in the rectal temperature difference. Thus a $4.16^{\circ}C$ increase in the dry bulb temperature results in approximately the same difference as working with and without a load.

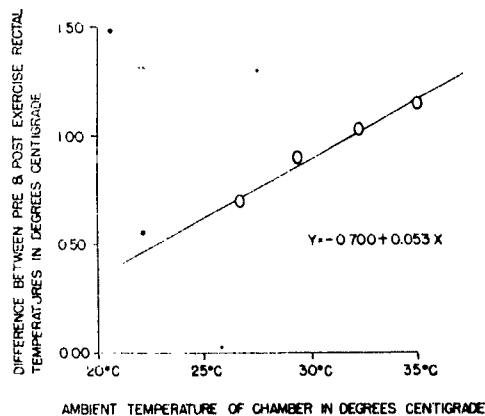AMBIENT TEMPERATURE OF CHAMBER IN DEGREES CENTIGRADE

FIGURE 2

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Skin Temperature

The difference between the pre- and post-exercise skin temperatures recorded in degrees centigrade was utilized as the raw data in performing the variance analysis. Results are summarized in Table 5(a). Since skin temperatures were measured simultaneously at four anatomical sites (forehead, chest, back, and right arm), a new source of variance termed "position" was introduced into the analysis. This, with its associated interactions, is itemized under conditions in Table 5(a).

As indicated in the analysis, significant changes in the pre- and post-exercise skin temperatures occurred between subjects as well as when morning (AM) and afternoon (PM) groups were compared. As shown in Table 5(a), the mean difference in skin temperatures for the morning group was significantly lower than the afternoon group. The experimental design used did not make it possible to test whether this represented true subject difference or resulted from a normal diurnal variation.

Analysis of the other sources of variation indicated that highly significant differences resulted from ambient temperature changes, various positions from which skin temperatures were taken, and between the conditions of load and no load.. It is noteworthy that the contribution to the variance resulting from wearing the load was approximately eight times that arising from differences in ambient temperature. The variability in response contributed by the position factor was approximately four times greater than that produced by ambient temperature changes. The interaction of temperature and load indicates that the response of load and no load at various temperatures differed in a significant manner. The same type of effect was noted for load x position interaction terms. In other words, the response from the four positions used to measure skin temperatures was affected in a significantly different manner by the presence or absence of BALCS.

Table 5(b) summarizes the condition means and their differences for each of the four groups and positions utilized. there was an increase in skin temperature differences as well as in the ambient temperature for each of the four anatomical sites. Regression analyses were performed in which the mean differences between the pre- and post-exercise skin temperatures expressed in degrees centigrade were plotted on the ordinate with the ambient temperature degrees centigrade plotted on the abscissa. Analyses for the four sites

Table 5

Analysis of Variance of Differences Between Pre- and Post-Skin Temperature Values in Degrees Centigrade

(a)

Source of Variation	df	Sum of Squares	Mean Squares	F
Subjects	5	43.3240	8.6648	9.197**
AM vs. PM	1	27.5276	27.5276	6.971**
Error	4	15.7964	3.9491	
Conditions	31	200.6124	6.4714	5.869**
Temperature	3	19.7827	6.5942	6.999**
Load	1	54.2938	54.2938	57.631**
Position	3	72.1702	24.0567	25.535**
Temperature x load	3	7.6022	2.5341	2.690*
Temperature x position	9	5.7621	0.6402	0.680
Load x position	3	23.9714	7.9905	8.482**
Temp. x load x position	9	17.0300	1.8922	2.008*
(AM vs. PM) x conditions	31	23.0374	0.7431	0.789
Residual	124	116.8236	0.9421	
Total	191	383.7974		

* Significant at 0.05 level.
** Significant at 0.01 level.

(b)

Summary of Condition Means and Differences

Position	Ambient Temperature																Overall Mean	Diff.	$SE_{Diff.}$
	26.7°C				29.4°C				32.2°C				35.0°C						
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4			
Load	+2.17	+3.37	+3.77	+1.45	+2.63	+3.15	+3.45	+2.35	+2.52	+2.95	+4.15	+3.17	+2.50	+4.67	+4.77	+3.18	+3.179	+1.065	±0.280
No Load	+0.55	+1.93	+1.92	+2.48	+0.68	+3.37	+3.06	+2.52	+1.59	+1.78	+1.92	+2.65	+1.25	+2.35	+3.07	+2.95	+2.114		
Overall Mean	+1.26	+2.65	+2.85	+1.98	+1.66	+3.26	+3.27	+2.34	+1.91	+2.87	+3.04	+2.91	+1.88	+3.51	+3.92	+3.07	+2.647		
Difference	+1.79	+1.44	+1.85	-1.01	+1.95	-0.22	+0.37	-0.37	+0.82	+2.17	+2.23	+0.52	+1.25	+2.32	+1.70	+0.23	+1.065		
$SE_{Diff.}$									±0.560										

(c)

Summary of Subject Means and Differences

	Subject No.	Subject Means	AM & PM Means	Diff.	$SE_{Diff.}$
AM	2	+2.58	+2.270	-0.757	±0.5737
	3	+2.01			
	4	+2.22			
PM	1	+2.78	+3.027		
	5	+3.49			
	7	+2.81			

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and back are shown in Figure 3; for the chest and right arm, in Figure 4. The results indicated the following:

1. Forehead: A $2.8^\circ C$ increase in the dry bulb temperature resulted in approximately a $0.20^\circ C$ increase in the skin temperature difference. Thus a $14.4^\circ C$ increase in dry bulb temperature was approximately equivalent to the difference in the increase of the skin temperature when BALCS is or is not worn.

2. Chest: A $2.8^\circ C$ increase in the dry bulb reading caused an increase in the skin temperature difference of approximately $0.22^\circ C$. Thus the wearing of BALCS resulted in an increase equivalent to that resulting from a $13.5^\circ C$ increase in the dry bulb temperature.

3. Back: An increase of $2.8^\circ C$ in the dry bulb reading resulted in a $0.30^\circ C$ increase in the skin temperature difference. Thus the wearing of BALCS causes approximately the same increase as raising the ambient temperature by $9.8^\circ C$.

4. Right Arm: Raising the ambient temperature by $2.8^\circ C$ causes an increase in skin temperature difference of approximately $0.39^\circ C$. Thus the increase when wearing BALCS approximates that resulting from increasing the ambient temperature $7.7^\circ C$.
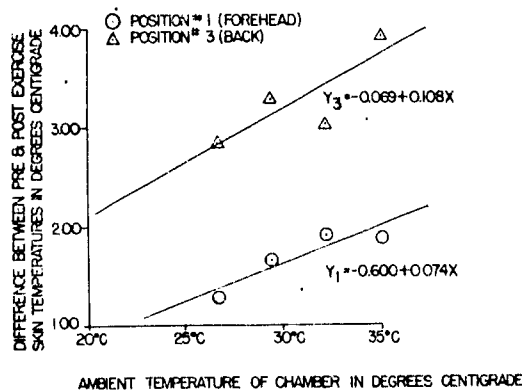

FIGURE 3

FIGURE 4

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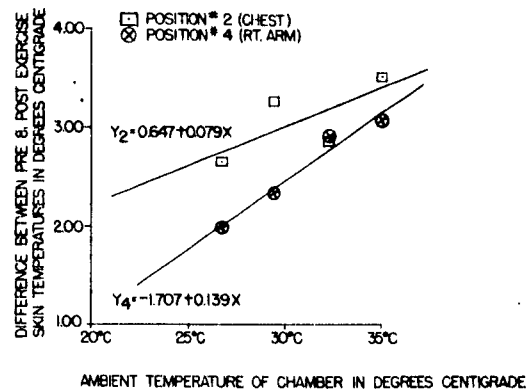## Heat Gain

The raw data for this analysis were heat gain values expressed as calories per kilogram body weight per 45 minutes computed from a formula cited in reference (5) and discussed in the section on Methods and Procedures. The results of the analysis of variance are shown in Table 6(a). The significant difference between subjects also contributed to the significance found between the morning and afternoon groups. It will be noted from Table 6(c) that the mean heat gain values for the morning subjects demonstrated remarkable uniformity and were in each case lower than the values found for the afternoon group. Since the experimental design did not permit randomizing the subjects between morning and afternoon periods, this finding cannot be definitely accepted as evidence for a diurnal variation as it may be a reflection of subject differences.

Both temperature and load resulted in significant changes in heat gain. When the relative effects of temperature and load are compared, the contribution arising from wearing the body armor and the pack is found to be approximately four times greater than the contribution resulting from the ambient temperatures. None of the remaining interaction terms produced any significant F ratios.

Table 6(b) presents the mean heat gain values for the eight conditions employed. In general, a progressive increase in heat gain occurred with increases in ambient temperature for both the load and no-load situations. On the average, when the subjects were wearing body armor and carrying a pack, the heat gains were approximately 0.40 cal/kg/45 min. greater than under the condition of no load. No specific reason can be suggested for the decrease which occurred at $32.2^{\circ}C$ with no load except to point out that other reversals were noted for pulse rates, skin temperatures, sweat loss, lactic acids, etc.

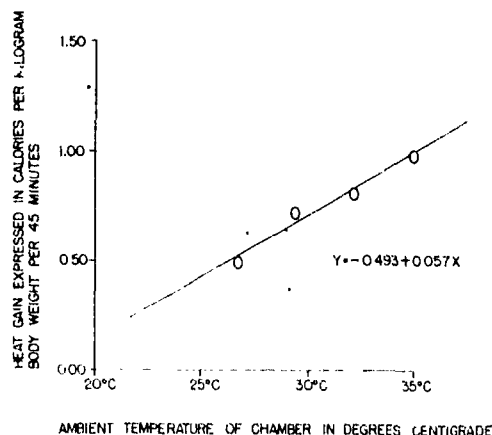AMBIENT TEMPERATURE OF CHAMBER IN DEGREES CENTIGRADE

FIGURE 5

Results of regression analysis between the mean heat gains and the ambient temperature (Figure 5) indicate that a $2.8^{\circ}C$ increase in the ambient dry bulb temperature produced a heat gain of approximately 0.16 cal/kg/45 min. Thus a $7.34^{\circ}C$ increase in dry bulb temperature was equivalent to the difference between working with and without the BALCS.

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Sweat Loss

In the analysis of variance for this variable the raw data used were the differences between the pre- and post-exercise body weight loss expressed in kilograms per 45 minutes. These results are summarized in Table 7(a). As indicated, no significant differences were found in sweat loss for the two main effects, subjects and conditions. In addition, the differences between the morning and afternoon groups (AM vs. PM) were not significantly different nor were any of the interaction terms. However, both temperature and load had a statistically significant effect ($P = 0.05$) on sweat loss.

The condition means and their differences are shown in Table 7(b). In general, there occurred an increase in the amount of sweat loss as a function of ambient temperature for both the load and no-load conditions with the latter situation yielding approximately 0.259 kg/45/min. less sweat. The mean sweat loss expressed in kilograms per 45 minutes was plotted as the ordinate against the ambient temperature in degrees centigrade on the abscissa. A regression analysis (Figure 6) revealed that an increase of $2.8^{o}C$ in dry bulb reading resulted in an increase in sweat loss of approximately 0.15 kilograms per 45 minutes. Thus the sweat loss incurred from wearing the BALCS and pack is equivalent to that expected from increasing ambient temperature $4.8^{o}C$.
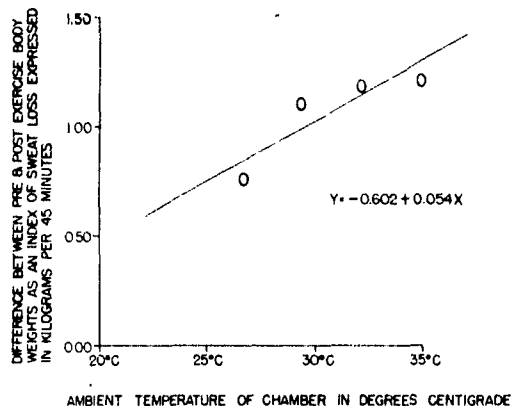

AMBIENT TEMPERATURE OF CHAMBER IN DEGREES CENTIGRADE

FIGURE 6

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Table 7

Analysis of Variance of Differences Between Pre- and Post-Exercise
(a) Body Weights As an Index of Sweat Loss in kg Per 45 Minutes

Source of Variation	df	Sum of Squares	Mean Squares	F
Subjects	5	0.6596	0.1319	0.781
AM vs. PM	1	0.3151	0.3151	3.660
Error	4	0.3445	0.0861	
Conditions	7	2.4257	0.3465	2.053
Temperature	3	1.5406	0.5135	3.042*
Load	1	0.8006	0.8006	4.743*
Temperature x load	3	0.0845	0.0282	0.167
(AM vs. PM) x conditions	7	0.2592	0.0370	0.219
Residual	28	4.7262	0.1688	
Total	47	8.0707		

*Significant at 0.05 level.

(b)   Summary of Condition Means and Differences

	Ambient Temperature				Overall Mean	Diff.	$SE_{Diff.}$
	26.7° C	29.4° C	32.2° C	35.0° C			
Load	+0.878	+1.214	+1.379	+1.291	+1.191	+0.259	±0.119
No Load	+0.639	+0.987	+0.982	+1.120	+0.932		
Overall Mean	+0.759	+1.101	+1.181	+1.206	+1.062		
Difference	+0.239	+0.227	+0.397	+0.171	+0.259		
$SE_{Diff.}$	±0.237						

(c)   Summary of Subject Means and Differences

	Subject No.	Subject Means	AM & PM Means	Diff.	$SE_{Diff.}$
AM	2	+0.942	+0.980	-0.162	±0.085
	3	+0.864			
	4	+1.134			
PM	1	+1.184	+1.142		
	5	+1.151			
	7	+1.091			

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Blood Lactic Acids

The differences between the pre- and post-exercise blood lactic acid values expressed in milligrams per 100 milliliters of blood were used as the raw data for this analysis. The results are summarized in Table 8(a). It will be noted that no significant differences were found between subjects or between the morning and afternoon groups. The other main source of variation (conditions) showed a difference at the 0.05 level of significance. Within this condition the temperature component produced significant (0.05) changes in the blood lactate differences. However, the addition of the BALCS, just as in the case of pulse rate, did not significantly affect the pre- and post-exercise blood lactic acid differences. The interaction term (AM and PM) x condition was significant at the 0.01 level. This suggested that the morning and afternoon groups were responding in a significantly different fashion to the various conditions. Table 8(b) contains the condition means and their differences. It will be noted that no systematic change in blood lactic acid levels as a function of ambient temperature is present. However, seven of the eight mean difference values are negative in sign, indicating that the post-exercise blood lactate levels were lower than the pre-exercise levels for these cases. A regression analysis did not appear warranted for this variable. Table 8(c) summarizes subject mean differences; again no systematic response pattern is noted.

Eosinophils

The data used for this analysis were the differences between the pre- and post-exercise eosinophil counts expressed per cubic millimeter of blood. As indicated in Table 9(a) no significant differences in eosinophil counts were noted in the study. Table 9(b) contains the means and their differences for the various conditions. No consistent response pattern as a function of ambient temperature was noted for this variable. In general, a greater difference between the pre- and post-exercise eosinophil counts occurred when the subjects were wearing the BALCS as compared to the no-load condition. The subject mean differences shown in Table 9(c) reflect the great variability in response between subjects for this physiological parameter.

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Table 8

Analysis of Variance of Differences Between Pre- and Post-Exercise Blood Lactic Acid Values in mg/100 ml

(a)

Source of Variation	df	Sum of Squares	Mean Squares	F
Subjects	5	120.1200	24.0240	0.689
AM vs. PM	1	11.6033	11.6033	0.428
Error	4	108.5167	27.1292	
Conditions	7	740.3192	105.7599	3.034*
Temperature	3	465.1142	155.0381	4.447*
Load	1	103.2533	103.2533	2.962
Temperature x load	3	171.9517	57.3172	1.644
(AM vs. PM) x conditions	7	868.8233	124.1176	3.560**
Residual	28	976.0900	34.8604	
Total	47	2705.3525		

* Significant at 0.05 level.
** Significant at 0.01 level.

(b)   Summary of Condition Means and Differences

	Ambient Temperature				Overall Mean	Diff.	$SE_{Diff.}$
	26.7° C	29.4° C	32.2° C	35.0° C			
Load	-7.33	-8.10	-5.77	-9.82	-7.76		
No Load	-6.22	-1.52	+0.67	-12.22	-4.82	-2.93	±1.704
Overall Mean	-6.78	-4.81	-2.55	-11.02	-6.29		
Difference	-1.11	-6.58	-6.44	+2.40	-2.93		
$SE_{Diff.}$	±3.409						

(c)   Summary of Subject Means and Differences

	Subject No.	Subject Means	AM & PM Means	Diff.	$SE_{Diff.}$
AM	2	-7.75			
	3	-5.31	-6.78		
	4	-7.28		-0.98	±1.504
PM	1	-7.00			
	5	-3.19	-5.80		
	7	-7.20			

Table 9

Analysis of Variance of Differences Between Pre- and Post-Exercise
Eosinophil Counts (per cubic millimeter of blood)

(a)

Source of Variation	df	Sum of Squares	Mean Squares	F
Subjects	5	6149.2500	1229.8500	0.428
AM vs..PM	1	140.0833	140.0833	0.093
Error	4	6009.1667	1502.2917	
Conditions	7	11987.3333	1712.4762	0.596
Temperature	3	8204.0000	2734.6667	0.951
Load	1	3201.3333	3201.3333	1.113
Temperature x load	3	582.0000	194.0000	0.067
(AM vs. PM) x conditions	7	36303.9167	5186.2738	1.804
Residual	28	80501.5000	2875.0536	
Total	47	134942.0000		

(b)   Summary of Condition Means and Differences

	Ambient Temperature				Overall Mean	Diff.	$SE_{Diff.}$
	26.7° C	29.4° C	32.2° C	35.0° C			
Load	-33.50	-13.17	-37.00	-15.00	-24.67	+16.33	±15.48
No Load	-15.17	+13.17	-29.67	-1.67	-8.34		
Overall Mean	-24.34	0.0	-33.34	-8.34	-16.51		
Difference	+18.33	+26.34	+7.33	+13.33	+16.33		
$SE_{Diff.}$	±30.96						

(c)   Summary of Subject Means and Differences

	Subject No.	Subject Means	AM & PM Means	Diff.	$SE_{Diff.}$
AM	2	-22.50			
	3	+1.25	-18.21		
	4	-33.38		-3.42	±11.19
PM	1	-23.63			
	5	-12.25	-14.79		
	7	-8.50			

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Urinary Electrolytes

Sodium and potassium ions: Both of these urinary ions were subjected to separate analyses of variance and the results are summarized in Table 10(a) for sodium and Table 11(a) for potassium. The raw data utilized were the differences between the pre- and post-exercise values expressed in meq/liter. As noted, none of the main effects or any of the interaction terms proved to be of statistical significance for either the sodium or potassium ions. Examination of the condition and subject means shown in Tables 10(b), 11(b), 10(c), and 11(c), for the urinary sodium and potassium differences, respectively, attest to the high variability which characterizes these measures. In general, these results indicate that following the exercise there was a decrease in the concentration of sodium ions and an increase in that of the potassium ions.

Sodium-potassium ratios: The raw data for this variable were the differences between the pre- and post-exercise Na/K ratios. The results of the analysis of variance (Table 12(a)) show that a statistically significant difference (0.01 level) for this derived variable occurred between subjects. Factors such as time of day, temperature, and load failed to produce any effect other than would be expected to arise from chance occurrences. The interaction of time of day with conditions ([AM vs. PM] x conditions) was significant at the 0.01 level of probability. It would appear from this that the factors of temperature and load affected the morning and afternoon groups in a significantly different manner. As in Table 12(b) six of the eight condition mean differences showed a decrease in the Na/K ratio, though not of sufficient magnitude to be of statistical significance. The variability of subject response can be seen in Table 12(c) where the individual subject mean differences for the Na/K ratios are recorded.

Salivary Electrolytes

Sodium and potassium ions: Tables 13(a) and 14(a) summarize the results of an analysis of variance for salivary sodium and potassium ions, respectively. The raw data utilized in these computations were the differences expressed in meq/liter between the pre-exercise and post-exercise measures. The only factor of statistical significance (0.05 level) was differences between subjects found for salivary sodium (Table 13(a)) although the magnitude of the F ratios for AM vs. PM differences for both ions and for subjects in the case of salivary

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Table 10

Analysis of Variance of Differences Between Pre- and Post-Exercise Urinary Sodium Values in meq/liter

(a)

Source of Variation	df	Sum of Squares	Mean Squares	F	
Subjects	5	7471.3542	1494.2708	1.535	
AM vs. PM	1	200.9008	200.9008		0.111
Error	4	7270.4534	1817.6134		
Conditions	7	4041.2433	577.3205	0.593	
Temperature	3	1973.9650	657.9883		0.676
Load	1	124.1633	124.1633		0.128
Temperature x load	3	1943.1150	647.7050		0.665
(AM vs.PM) x conditions	7	5943.1225	849.0175	0.872	
Residual	28	27261.1067	973.6110		
Total	47	44716.8267			

(b)   Summary of Condition Means and Differences

	Ambient Temperature				Overall Mean	Diff.	SE$_{Diff.}$
	26.7° C	29.4° C	32.2° C	35.0° C			
Load	+2.50	-25.58	-6.75	-2.67	-8.13	-3.22	±9.007
No Load	+3.00	-3.67	-2.50	-16.47	-4.91		
Overall Mean	+2.75	-14.63	-4.63	-9.57	-6.52		
Difference	-0.50	-21.91	-4.25	+13.80	-3.22		
SE$_{Diff.}$	±18.015						

(c)   Summary of Subject Means and Differences

	Subject No.	Subject Means	AM & PM Means	Diff.	SE$_{Diff.}$
AM	2	-18.13			
	3	-14.88	-8.57		
	4	+7.31		-4.10	±12.31
PM	1	-16.50			
	5	+13.96	-4.47		
	7	-10.88			

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Table 11

Analysis of Variance of Differences Between Pre- and Post-Exercise Urinary Potassium Values in meq/liter

(a)

Source of Variation	df	Sum of Squares	Mean Squares	F
Subjects	5	13051.4575	2610.2915	2.288
AM vs. PM	1	3884.4008	3884.4008	1.695
Error	4	9167.0567	2291.7642	
Conditions	7	5385.6533	769.3790	0.674
Temperature	3	688.5783	229.5261	0.201
Load	1	242.1008	242.1008	0.212
Temperature x load	3	4454.9742	1484.9914	1.302
(AM vs. PM) x conditions	7	15969.0826	2281.2975	2.000
Residual	28	31941.5766	1140.7706	
Total	47	66347.7700		

(b)   Summary of Condition Means and Differences

	Ambient Temperature				Overall Mean	Diff.	SE$_{Diff.}$
	26.7° C	29.4° C	32.2° C	35.0° C			
Load	+30.58	+12.25	+27.25	+4.00	+18.52	+4.49	±9.750
No Load	+3.58	+28.98	+7.17	+16.38	+14.03		
Overall Mean	+17.08	+20.62	+17.21	+10.19	+16.28		
Difference	+27.00	-16.73	+20.08	-12.38	+4.49		
SE$_{Diff.}$	±19.500						

(c)   Summary of Subject Means and Differences

	Subject No.	Subject Means	AM & PM Means	Diff.	SE$_{Diff.}$
AM	2	+48.25			
	3	+24.13	+25.27		
	4	+3.44		+17.99	±13.820
PM	1	+16.60			
	5	+4.80	+7.28		
	7	+0.44			

Table 12

Analysis of Variance of Differences Between Pre- and Post-Exercise
Urinary Sodium-Potassium Ratios

(a)

Source of Variation	df	Sum of Squares	Mean Squares	F
Subjects	5	6.6165	1.3233	3.921**
AM vs. PM	1	0.4953	0.4953	0.324
Error	4	6.1212	1.5303	
Conditions	7	2.0875	0.2982	0.884
Temperature	3	1.3003	0.4334	1.284
Load	1	0.0021	0.0021	0.006
Temperature x load	3	0.7851	0.2617	0.775
(AM vs. PM) x conditions	7	8.0854	1.1551	3.423**
Residual	28	9.4493	0.3375	
Total	47	26.2387		

**Significant at 0.01 level.

(b)   Summary of Condition Means and Differences

	Ambient Temperature				Overall Mean	Diff.	$SE_{Diff.}$
	26.7° C	29.4° C	32.2° C	35.0° C			
Load	-0.310	-0.423	-0.429	+0.139	-0.256	-0.013	±0.168
No Load	+0.047	-0.389	-0.403	-0.226	-0.243		
Overall Mean	-0.132	-0.406	-0.416	-0.044	-0.250		
Difference	-0.357	-0.034	-0.026	+0.365	-0.013		
$SE_{Diff.}$	±0.335						

(c)   Summary of Subject Means and Differences

	Subject No.	Subject Means	AM & PM Means	Diff.	$SE_{Diff.}$
AM	2	-0.412	-0.351	-0.203	±0.357
	3	-0.688			
	4	+0.047			
PM	1	-0.688	-0.148		
	5	+0.285			
	7	-0.040			

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potassium tended to approach statistical significance. Again, examination of the condition means for salivary sodium and potassium differences, shown in Tables 13(b) and 14(b), respectively, failed to reveal any systematic trend in response as a function of either temperature or load. This was also true of the subject means shown in Tables 13(c) and 14(c). The same tendency for sodium to show a decrease and potassium an increase for urine was also true for saliva.

Sodium-potassium ratios: The raw data for the analysis of variance performed on the salivary Na/K ratios were values representing the difference between the pre-exercise ratio and the post-exercise ratio computed for each subject for each of the eight conditions (Table 15(a)). The only factor which proved to be of statistical significance (0.01 level) was that arising from differences between subjects. Furthermore, examination of the condition means reported in Table 15(b) failed to reveal any systematic trend in response as a result of either ambient temperature or the weight which the subjects carried. It is interesting to note that the subject means reported in Table 15(c) show that the decrease in the salivary Na/K ratio difference for the morning subjects was approximately ten times that of the afternoon group. Here again the lack of statistical significance is attributed to the large variation in response of the individual subjects combined with the small sample studied.

DISCUSSION

Under conditions of high temperature, high relative humidity, and increased activity, the addition of a protective garment imposes strains on two important physiological parameters: cardiovascular function and temperature regulation. In this connection, it has often been pointed out that in thermal stress this represents at least synergism and probably even potentiation since exercise and heat independently and simultaneously impose strains on both cardiovascular function and temperature regulation. The object of the present study was to determine the extent of such stress imposed by a body armor-load carrying system when used with a load of approximately 54 pounds.

In terms of time, all of the subjects were able to complete their exercise on the treadmill for 45 minutes at each of the four temperature conditions, both with and without load. At no time did any of the subjects attain body temperatures above 39°C or pulse rates greater than 180 beats per minute.

Table 13

Analysis of Variance of Differences Between Pre- and Post-Exercise
Salivary Sodium Values in meq/liter

(a)

Source of Variation	df	Sum of Squares	Mean Squares	F
Subjects	5	2151.8835	430.3767	3.561*
AM vs. PM	1	890.1019	890.1019	2.822
Error	4	1261.7816	315.4454	
Conditions	7	593.0931	84.7276	0.701
Temperature	3	180.7856	60.2619	0.499
Load	1	74.7502	74.7502	0.618
Temperature x load	3	337.5573	112.5191	0.931
(AM vs. PM) x conditions	7.	458.8965	65.5566	0.542
Residual	28	3384.3317	120.8690	
Total	47.	6588.2048		

*Significant at 0.05 level.

(b)   Summary of Condition Means and Differences

	Ambient Temperature				Overall Mean	Diff.	SE$_{Diff.}$
	26.7° C	29.4° C	32.2° C	35.0° C			
Load	-1.13	-1.83	+8.92	-1.27	+1.17	+2.50	±3.174
No Load	+0.43	-2.27	-2.68	-0.78	-1.33		
Overall Mean	-0.35	-2.05	+3.12	-1.03	-0.08		
Difference	-1.56	+0.44	+11.60	-0.49	+2.50		
SE$_{Diff.}$	±6.347						

(c)   Summary of Subject Means and Differences

	Subject No.	Subject Means	AM & PM Means	Diff.	SE$_{Diff.}$
AM	2	+4.55	-4.383	-8.610	±5.127
	3	-9.91			
	4	-7.79			
PM	1	+6.83	+4.230		
	5	-0.65			
	7	+6.51			

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Table 14

Analysis of Variance of Differences Between Pre- and Post-Exercise Salivary Potassium Values in meq/liter

(a)

Source of Variation	df	Sum of Squares	Mean Squares	F
Subjects	5	372.8869	74.5774	2.517
AM vs. PM	1	141.7969	141.7969	2.454
Error	4	231.0900	57.7725	
Conditions	7	206.3981	29.4854	0.995
Temperature	3	144.6956	48.2319	1.628
Load	1	17.6419	17.6419	0.595
Temperature x load	3	44.0606	14.6869	0.496
(AM vs. PM) x conditions	7	232.4081	33.2012	1.121
Residual	28	829.5300	29.6261	
Total	47	1641.2231		

(b)   Summary of Condition Means and Differences

	Ambient Temperature				Overall Mean	Diff.	$SE_{Diff.}$
	26.7° C	29.4° C	32.2° C	35.0° C			
Load	-0.20	+0.35	+4.65	+4.25	+2.26	-1.22	±1.571
No Load	+3.40	+1.70	+6.30	+2.50	+3.48		
Overall Mean	+1.60	+1.03	+5.48	+3.38	+2.87		
Difference	-3.60	-1.35	-1.65	+1.75	-1.22		
$SE_{Diff.}$	±3.143						

(c)   Summary of Subject Means and Differences

	Subject No.	Subject Means	AM & PM Means	Diff.	$SE_{Diff.}$
AM	2	-2.89	+1.150	-3.437	±2.194
	3	+2.59			
	4	+3.75			
PM	1	+3.26	+4.587		
	5	+4.50			
	7	+6.00			

Table 15

Analysis of Variance of Differences Between Pre- and Post-Exercise Salivary Sodium-Potassium Ratios

(a)

Source of Variation	df	Sum of Squares	Mean Squares	F
Subjects	5	16.4703	3.2941	4.004**
AM vs. PM	1	1.9927	1.9927	0.551
Error	4	14.4776	3.6194	
Conditions	7	2.5274	0.3611	0.439
Temperature	3	0.2975	0.0992	0.121
Load	1	0.7203	0.7203	0.876
Temperature x load	3	1.5096	0.5032	0.612
(AM vs PM) x conditions	7	3.0847	0.4407	0.536
Residual	28	23.0323	0.8226	
Total	47	45.1147		

** Significant at 0.01 level.

(b) **Summary of Condition Means and Differences**

	Ambient Temperature				Overall Mean	Diff.	$SE_{Diff.}$
	26.7° C	29.4° C	32.2° C	35.0° C			
Load	-0.140	-0.370	+0.270	-0.270	-0.128	+0.242	±0.262
No Load	-0.260	-0.360	-0.580	-0.280	-0.370		
Overall Mean	-0.200	-0.365	-0.155	-0.275	-0.249		
Difference	+0.120	-0.010	+0.850	+0.010	+0.242	·	
$SE_{Diff.}$	±0.524						

(c) Summary of Subject Means and Differences

	Subject No.	Subject Means	AM & PM Means	Diff.	$SE_{Diff.}$
AM	2	+0.56	-0.453		
	3	-0.99			
	4	-0.93		-0.410	±0.549
PM	1	+0.19	-0.043		
	5	-0.46			
	7	+0.14			

The ability of these subjects to tolerate a similar exercise more than twice as long as the Army group studied by Goddard et al. (1) may be a reflection of their superior physical condition. Improvement in physical fitness was achieved during their conditioning period prior to exercising in the climatic chamber and was indicated by improved performance in both the "Step Test" (3) and the Physical Fitness Test (4).

Further evidence of increased fitness was sought by measurements of blood lactic, acid levels. In this connection it has been suggested that one of the many factors which may determine the lactate response of an individual to a given workload is the individual's exercise tolerance (physical fitness). The modification of lactic acid response by a training program is considered reliable enough by Johnson and Brouha (9) to be included as an index of physical fitness.

In the present study we were not able to demonstrate any modification of the lactic acid response. The average resting level for the six subjects prior to their physical fitness program was 11.3 milligrams per cent. At the end of this 2-week conditioning period, the average blood lactate level had not changed significantly for the group (11.9 milligrams per cent). Similar results were reported by Robinson and Harmon (10) who found that strenuous athletic training for 6 months did not affect the lactic acid and blood sugar levels.

A review of the blood lactate levels resulting from the exercise indicates that in all but one instance (32.2°C - no load), the lactic acid values decreased following exercise when compared to the pre-exercise levels. This observation is interesting in view of the controversy in the literature regarding the general subject of lactic acid in relation to exercise. For example, it is generally accepted that with the onset of exercise, there is a rapid increase in the blood lactate concentration to a maximum level (11). Hill et al. (12) state that once the maximum has been attained, the concentration remains at the same level as long as exercise is continued at the same rate. Bang (11), however, reported that blood lactate decreases even though activity is continued in a steady state. Crescitelli and Taylor (13) reported that only 2 of their 20 subjects who walked on a treadmill for 15 minutes at the rate of 100 meters per minute with a 15 per cent incline showed higher blood lactate concentrations within 2 minutes after the cessation of activity than the peak value during the walk. All others had reached their peak before the cessation of the walk and levels had started to decline. These investigators suggest that lactate production begins immediately after the onset of exercise, rises to a maximum, and then declines without attaining a steady level for any significant period of time. No equilibrium condi-

tions are apparently set up between lactate of production and dissipation; rather the lactate appears related to a period of adjustment associated with the beginning of activity. Our results are in agreement with these findings.

Although higher temperatures caused significant differences in the pre- and post-exercise pulse rates, the addition of body armor at the temperatures tested did not cause a significant change in the pulse rate. It would appear from this that the wearing of BALCS did not significantly increase the pulse rate beyond that already imposed by temperature. It is of further interest to note that at these temperatures, high humidity, and workload, the pulse rate did not exceed 180 beats per minute at any time during the 45 minutes of the exercise period. In addition, although no records were kept, individual pulse rates were routinely counted 3 minutes post-exercise and all showed a decrease in pulse rate of at least 40 beats per minute. This indicated excellent cardiovascular recovery.

In the analysis of the effect of ambient temperature and load on body temperature, it was found that both of these conditions independently caused increases in rectal temperature.

Significant increases in skin temperature occurred at each of the areas measured. This increase was found to be caused independently by both temperature and load. In this connection, Robinson and Gerking (14) reported that a rise in skin temperature with increasing effective temperature is uniformly greater than the rise in rectal temperature with the net result that the gradient between rectal temperature and skin temperature is progressively reduced as the ambient temperature rises.

Our study indicated a progressive decrease in temperature gradient with increase in ambient temperature; both with and without load, as shown in the tabulation given below. Thus, at 26.7°C, the temperature gradient was 2.46°C; at 35°C, it had decreased to 1.32°C. When body armor was used at these temperatures, a greater decrease occurred in the gradient between skin temperature and rectal temperature. For example, at 26.7°C, the gradient was 1.56°C; at 35.0°C, it was 1.00°C.

Thermal Gradient Between Skin and Rectal Temperature.

	26.7° C	29.4° C	32.2° C	35.0° C
Load	1.56	1.23	· 1.16	1.00
No Load	2.46	2.42	1.71	1.32

The progressive increase in sweating with increases in temperature and the addition of load indicated is in agreement with the findings of other investigators (15). In this connection, the decrease in sweat loss, which occurred when three of the subjects exercised at the extreme condition (namely, 35. 0°C while wearing the body armor-load carrying system), was of particular interest. This diminished sweat rate along with the increases in the skin and rectal temperatures suggested that these individuals had reached their physiological limits and that longer exposure might bring on heat exhaustion.

The assessment of adrenal cortical activity, as indicated by measurements utilized in this study, indicated that neither the work nor the heat was of sufficient magnitude to cause a measurable stress. In this connection it has been reported that heat appears to induce a variable response in adrenal cortical activity depending on its intensity. Robinson and MacFarlane (16) report that exercise in a neutral thermal environment appears to be insufficient as a stimulus to adrenal cortical secretion. Damanski et al. (17), in reporting on the eosinophil response to muscular activity, found little or no decrease in eosinophil level when subjects worked to exhaustion on a treadmill.

The results of this study tend to confirm the findings of others as to the variability of the response of the adrenal cortex to heat and similarly the variability of this index to muscular activity. For example, a measurement of circulating eosinophils in this study indicated that a decreased eosinophil count occurred in all conditions except at 29. 4°C with the load. Thus eosinopenia was greater when the effect of load was analyzed, but neither condition, however, caused significant changes in the number of circulating eosinophils.

The use of sodium-potassium ratios in urine as an assessment of adrenal cortical activity has been suggested by other investigators. Davis and Taylor (18) contend that expressing sodium and potassium as ratios not only permit the values for these materials to be determined without the necessity of accurate collection time or restricting water intake but in addition makes it unnecessary to take into account large variations in absolute levels.

In this connection, MacFarlane (19) reported that the exposure of subjects to 41. 0°C shifts the Na/K in urine from 1. 4 to 0. 4. He associated this with a higher output of aldosterone during heat stress. Bass et al. (20) reported that with subjects exposed at 102°F and 28 per cent relative humidity, the Na/K ratio in urine fell markedly from control values during the first 4 days, rose to higher than control values on the sixth and eighth days, and then fell gradually to preheat values.

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It would appear then that although the results here indicate a trend toward sodium retention and increased potassium excretion, the stress of temperature and load in these exercises was not severe enough to stimulate increased adrenal cortical activity. Another possible explanation for the failure of the Na/K ratio to show a significant pattern may be the undetermined electrolytes in the sweat, coupled with the failure to control the diet of the men.

The increased retention of sodium and increased excretion of potassium during heat stress has been associated with a higher output of aldosterone (21). This hormone has been demonstrated to depress Na/K salivary ratio (22). Thus it has been suggested that a relatively simple method to evaluate the effects of heat stress is to collect samples of saliva and examine them for sodium and potassium levels.

Here again, as in the urine samples, no significant difference occurred between the pre- and post-exercise sodium-potassium ratio differences of the salivary fluid which would indicate significant increased adrenal cortical activity. It would appear, however, that further study of this method for assessment of adrenal cortical activity should continue because the utilization of this method may prove just as accurate and certainly simpler in determining the effect of heat stress than the use of either urine or blood.

SUMMARY AND CONCLUSIONS

This study was undertaken to assess the stress on the operational efficiency of Marine Corps infantrymen resulting from wearing a Naval Medical Field Research Laboratory integrated body armor-load carrying system (BALCS) with load at high temperatures and high relative humidity.

Following a 2-week period of physical conditioning, six young Marine Corps volunteers exercised on a treadmill positioned for a 3 per cent grade and rotating at 3.5 miles per hour. The exercise was carried out for period of 45 minutes at dry bulb temperatures of 26.7, 29.4, 32.2, and 35.0 degrees centigrade and at a constant relative humidity of 75 per cent. The subjects were tested at each of these four environmental conditions with and without BALCS with load; the latter was the equivalent of 54 pounds.

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A modified Latin Square design was employed in the study (8 test situations and 8 experimental days). Differences in subject response prior to and following the exercise were measured for pulse rate, rectal and skin temperatures, heat gain, sweat loss, and lactic acid in blood. In addition, eosinophil counts and sodium and potassium levels in urine and saliva were determined in order to assess the effect of the test situations on the activity of the adrenal cortex. The differences in pre- and post-exercise measurements served as the raw data for each of the physiological parameters, and the statistical procedure was to subject the differences to an analysis of variance.

The results indicated that the addition of a body armor-load carrying system weighing 54 pounds (BALCS) had relatively little effect on the differences between pre- and post-exercise pulse rate s; the average increase was only 2.58 beats per minute. From regression analyses it was calculated that the difference between exercising with and without BALCS gave approximately the same increase in pulse rate as would result from an increase of $1.99^{\circ}C$ in dry bulb temperature, the same increase in rectal temperature as would result from an increase of $4.16^{\circ}C$ in dry bulb temperature, and the same increase in heat gain as would result from an increase of $7.34^{\circ}C$ in dry bulb temperature. Skin temperature differences following exercise occurred in all four anatomical sites measured; these were roughly the equivalent of increases in dry bulb temperature of $14.4^{\circ}C$ on the forehead, $13.5^{\circ}C$ on the chest, $9.8^{\circ}C$ on the back, and $7.7^{\circ}C$ on the right arm. The sweat loss incurred from wearing BALCS was approximately that expected from a $4.8^{\circ}C$ rise in dry bulb temperature.

Ambient temperature changes produced significantly lower blood lactic acid levels following exercise, but the changes were not systematic, and the wearing of BALCS did not significantly affect the difference in these levels. There was no consistent pattern in response of oesinophils although there was a greater difference between the pre- and post-exercise counts when subjects wore BALCS. In general, there was a decreased concentration of sodium ions and an increased concentration of potassium ions following the exercise. This finding held for both urinary and salivary electrolytes, and the changes in concentration typically were more marked when subjects wore BALCS.

The changes in physiological parameters attributable to the wearing of BALCS were statistically significant for rectal and skin temperatures, heat gain, and sweat loss. However, the magnitude of the increases was within normal physiological limits. Subjects approached unsafe limits only at the extreme exercise condition (wearing BALCS at $35.0^{\circ}C$) and for only the sweat loss variable; all subjects

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were able to complete the exercise periods. Accordingly, it is concluded that the wearing of BALCS did not unduly affect operational efficiency under the conditions of this study.

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APPENDIX

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Table A-1

Vital Statistics and Body Measurements of Test Subjects

Subject	Age (yr)	Height (cm)	Weight (kg)	Surface Area (sq. meters)	Per Cent Body Fat	Lean Body Mass
M. D.	19.2	169.5	60.8	1.79	8.2	55.81
E. F.	22.4	171.5	67.6	1.79	7.1	62.80
D. G.	21.3	166.4	64.5	1.71	9.2	58.57
J. M.	24.2	173.4	65.8	1.78	12.5	57.57
H. W.	21.5	181.0	77.2	1.98	12.0	67.94
T. M.	20.4	173.0	72.5	1.86	15.5	61.27

Table A-2

Experimental Design

		Order	Test Condition*	Subject No.			Order	Test Condition*	Subject No.
Day 1	AM	1	D_4L	2	Day 1	AM	1	D_1NL	2
		2	D_4NL	3			2	D_3L	1
		3	D_3NL	1			3	D_2NL	3
	PM	1	D_2NL	5		PM	1	D_2L	5
		2	D_1L	6			2	D_4L	6
		3	D_1NL	4			3	D_3NL	4
Day 2	AM	1	D_1NL	3	Day 2	AM	1	D_2L	2
		2	D_2L	1			2	D_3L	3
		3	D_4NL	2			3	D_1L	1
	PM	1	D_2NL	6		PM	1	D_4NL	5
		2	D_4L	4			2	D_2NL	4
		3	D_1L	5			3	D_3NL	6
Day 3	AM	1	D_1L	3	Day 3	AM	1	D_1NL	1
		2	D_2NL	2			2	D_3NL	3
		3	D_4L	1			3	D_1L	2
	PM	1	D_4NL	4		PM	1	D_1L	6
		2	D_1NL	5			2	D_4L	5
		3	D_3L	6			3	D_3L	4
Day 4	AM	1	D_2NL	1	Day 4	AM	1	D_3L	2
		2	D_3NL	2			2	D_4NL	1
		3	D_2L	3			3	D_4L	3
	PM	1	D_3L	4		PM	1	D_1NL	6
		2	D_4NL	6			2	D_2L	4
		3	D_3L	5			3	D_3NL	5

* D_1 = Dry bulb temperature of 35.0°C.
  D_2 = Dry bulb temperature of 32.2°C.
  D_3 = Dry bulb temperature of 29.4°C.
  D_4 = Dry bulb temperature of 26.7°C.
  L = Load.
NL = No Load.

Table A-3

(a) Analysis of Variance of the Effect of Days on Performance

Source of Variation	df	Sum of Squares	Mean Squares	F
Subjects	5	0.0000	0.0000	
AM vs. PM	1	0.0000	0.0000	
Error	4	0.0000	0.0000	
Conditions	7	42.6667	6.0952	0.769
Temperature	3	17.1667	5.7222	0.722
Load	1	12.0000	12.0000	1.514
Temperature x load	3	13.5000	4.5000	0.568
(AM vs.PM) x conditions	7	68.3333	9.7619	1.231
Residual	28	222.0000	7.9286	
Total	47	333.0000		

(b) Summary of Condition Means and Differences

	Ambient Temperature				Overall Mean	Diff.	SE$_{Diff.}$
	26.7° C	29.4° C	32.2° C	35.0° C			
Load	+5.83	+6.50	+6.17	+4.50	+5.75	+1.00	±0.813
No Load	+3.83	+6.00	+4.17	+5.00	+4.75		
Overall Mean	+4.83	+6.25	+5.17	+4.75	+5.25		
Difference	+2.00	+0.50	+2.00	-0.50	+1.00		
SE$_{Diff.}$	±1.626						

(c) Summary of Subject Means and Differences

	Subject No.	Subject Means	AM & PM Means	Diff.	SE$_{Diff.}$
AM	2	+5.25	+5.25	-0.00	±0.00
	3	+5.25			
	4	+5.25			
PM	1	+5.25	+5.25		
	5	+5.25			
	7	+5.25			

Table A-4

Pulse Rate (beats/min)

Temperature		26.7° C				29.4° C				32.2° C				35.0° C			
Condition		No Load		Load		No Load		Load		No Load		Load		No Load		Load	
		Rest	Final	Rest	Final	Rest	Final	Rest	Final	Rest	Final	Rest	Final	Rest	Final	Rest	Final
AM	Subject 2	72	114	80	116	68	127	96	147	88	123	96	151	80	134	86	140
	Subject 3	88	145	100	147	88	127	96	134	88	150	88	144	84	155	90	142
	Subject 4	84	131	78	128	84	134	68	114	80	133	84	134	96	145	80	142
PM	Subject 1	96	114	80	134	84	128	80	147	100	146	88	152	96	143	100	163
	Subject 5	88	140	96	160	76	149	97	145	104	163	100	160	84	144	108	163
	Subject 7	96	130	80	147	80	132	80	134	88	144	100	146	80	157	100	160
Average		87.3	129.0	85.7	138.7	80.0	132.8	85.3	136.8	91.3	143.2	92.7	147.8	86.7	146.3	94.0	151.7

Table A-5

Rectal Temperature (degrees centigrade)

Temperature		26.7° C				29.4° C				32.2° C				35.0° C			
Condition		No Load		Load		No Load		Load		No Load		Load		No Load		Load	
		Rest	Final	Rest	Final	Rest	Final	Rest	Final	Rest	Final	Rest	Final	Rest	Final	Rest	Final
AM	Subject 2	37.0	37.3	37.0	37.4	37.2	37.6	37.3	38.3	37.2	37.5	37.4	38.4	37.1	38.0	37.0	38.2
	Subject 3	37.2	37.9	37.4	38.4	36.8	37.7	37.1	37.7	36.9	38.2	37.2	38.2	37.3	38.7	37.1	37.9
	Subject 4	37.2	37.8	37.1	37.6	36.9	37.6	37.1	38.1	37.2	38.0	37.0	38.2	37.2	38.0	37.1	38.4
PM	Subject 1	37.3	38.2	37.5	38.6	37.1	38.3	37.6	38.8	37.6	38.8	37.2	38.6	37.5	38.5	37.2	39.0
	Subject 5	37.3	38.3	37.5	38.5	37.1	37.8	37.2	38.5	37.4	38.2	37.3	38.6	37.2	38.1	37.6	39.0
	Subject 7	37.4	37.8	37.4	37.9	37.2	38.0	37.5	38.5	37.2	38.1	37.2	38.3	37.4	38.5	37.4	38.5
Average		37.2	37.9	37.3	38.1	37.1	37.8	37.3	38.3	37.3	38.1	37.2	38.4	37.3	38.3	37.2	38.5

BODY ARMOR - LOAD CARRYING SYSTEM
(BALCS) WITH FULL LOAD

FIGURE A-1

The objective of this study was to determine the physiologic stress imposed on physically fit Marine Corps infantrymen when wearing the Naval Medical Field Research Laboratory body armor-load carrying system with full load (BALCS) (total weight, 54 pounds). Study was carried out under simulated tropical climatic conditions.

Subjects exercised on a treadmill positioned for a 3 per cent grade and rotating at 3.5 mph. This work was carried on for 45 minutes at dry bulb temperatures of 26.7, 29.4, 32.2, and 35.0 degrees centigrade with a constant relative humidity of 75 per cent. Men were tested at each of these four environmental conditions with and without BALCS. Total load carried by each subject was 54 pounds. The differences in pre- and post-exercise measurements served as the raw data for each of the physiological parameters, and the statistical procedure was to subject the differences to an analysis of variance.

The changes in physiological parameters attributable to the wearing of the BALCS with load were statistically significant for rectal and skin temperatures, heat gain, and sweat loss. However, the magnitude of the increase was within normal physiological limits. Subjects approached unsafe limits only at the extreme exercise condition (wearing BALCS with load at 35°C) and for only the sweat loss variable. Accordingly, it is concluded that the wearing of BALCS with load did not unduly affect the operational efficiency of these subjects under the conditions of this study.